Evolvable Systems Technology –
Automated Design and Optimization for NASA Exploration Missions

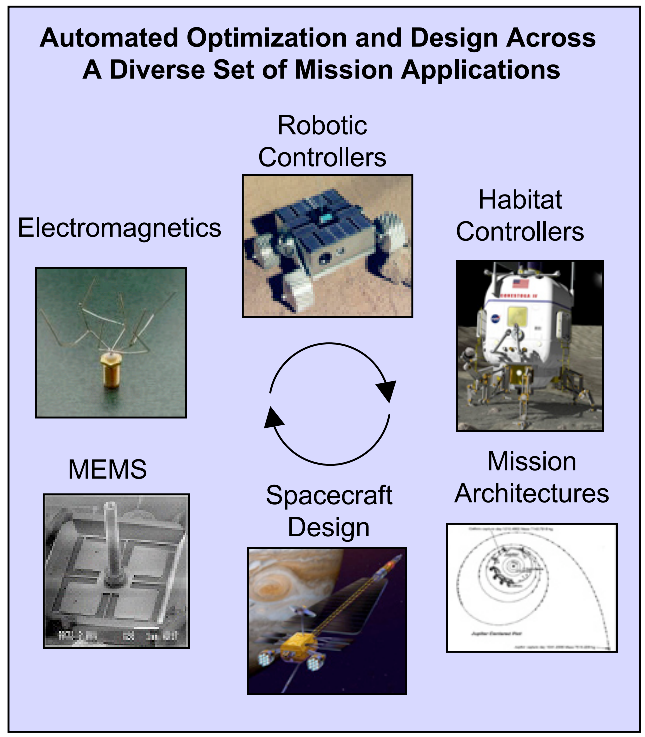
NASA Exploration Missions will require new advances in engineering design and optimization. Evolvable Systems technologies are poised to deliver these advances through the use of algorithms that can automatically design and optimize systems without being explicitly how told how to do so.

Background

Future NASA exploration missions will require advanced spacecraft architectures and hardware systems to achieve sustainability, affordability, and reliability. Critical to this goal is the need for advanced computer algorithms to manage the design complexity both for *static* design challenges on the ground (pre-launch) and *dynamic* design problems in space (post-launch). Exploration missions will require both hardware and software systems that can respond to and recover from component faults and failures and that can adapt, self-improve, self-repair, and self-reconfigure based on changing mission requirements and unexpected events.

The Evolvable Systems Group at NASA Ames Research Center investigates computer algorithms that automate the design and optimization of complex engineering systems for NASA exploration missions. The core technologies that we investigate are based on adaptive and evolutionary algorithm methods. The methods, which include genetic algorithms, genetic programming, artificial neural networks, simulated annealing, and variants thereof, have recently begun to produce human-competitive results in real-world application domains. As an example, in NASA's Space Technology 5 (ST5) mission requirements-compliant evolved antennas were produced and are scheduled to be flown in 2005 (Figures, page 2, bottom). The evolved antenna will be the first evolved hardware ever flown on a NASA mission. An initial design was as good as a human-designed model and outperformed it in critical metrics such as mass and cost. A second design was evolved in less than four weeks after an orbit change, proof that these techniques aid designers in adapting quickly to changing requirements.

The key application areas we investigate are outlined in the figure on this page and include: electromagnetics, MEMS, electronic controllers, self-repairing reconfigurable chips,



and mission profile design. Some of the specific applications we pursue include antenna radiator design, reconfigurable antennas, phasing and gain circuitry optimization and design, printable antennas, phased-array antenna design, launch vehicle structure, sensors, high-precision MEMS gyroscopes, mission planning tradeoff space analysis, rapid design / re-design cycles in response to changing mission requirements, and integration of automated design/optimization methods into computer aided design tools.

Research Overview

In addition to the automated design of antennas previously mentioned, another successful application area involves fault

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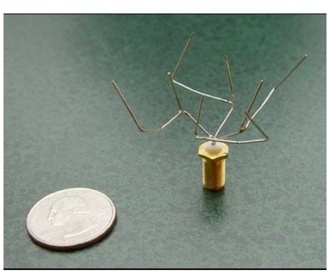
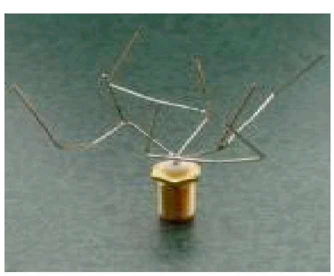
recovery for field-programmable gate arrays (FPGAs). An example scenario where such techniques are applied is when a spacecraft flies through an extreme radiation environment and is damaged by ionizing radiation causing a fault in one of its FPGAs. After the fault is detected, an evolutionary algorithm runs and quickly repetitively rewires the FPGA until the chip becomes functional again. It does this by exploiting healthy resources on the device, and sometimes even the damaged resources to regain a fully-functional chip.

Specific objectives of Evolvable Systems research are to develop automated design software that: a) dramatically increases the effectiveness of systems engineers and mission planners as compared to their current tools; b) allows FPGA devices to recover from radiation and temperature-induced faults, both transient and permanent in real-time; c) can automatically design high-precision MEMS gyroscopes for spacecraft navigation systems; d) can automatically design robotic and habitat controllers that operate autonomously; e) are able to design and optimize large-scale structures such as launch vehicles, spacecraft, rovers and habitat modules; e) are able to aid mission planners via automatic exploration and optimization across mission planning tradeoff spaces.

An additional advantage of our automated design algorithms is that they can design structures *in-situ*. By this we mean that an object can be designed inside the environment it will be deployed in. For example: antennas are designed to achieve a certain performance in free space, yet when an antenna is affixed to a spacecraft, the performance can be greatly affected by reflections of the signal off of the spacecraft. In our approach, we can evolve the antenna while it is affixed (in simulation) to the target spacecraft. By doing so, performance gains may be realized since the algorithm can exploit the physics of the environment it is working within. Other potential benefits are: smaller size, higher performance, lower cost, greater reliability.





Relevance to Exploration Systems

The benefits of the proposed technologies fall under sustainability, affordability, reliability, and modularity.

In order to realize a *sustainable* campaign of space exploration, the underlying technologies must enable affordable, reliable, and effective exploration and infrastructure systems. Evolvable Systems algorithms are highly adaptable, relatively fast, and can be set up to optimize cost, robustness, and performance by embedding these measures directly into the multi-objective utility functions that comprise the algorithms.

Evolvable Systems algorithms are relatively inexpensive to develop and can result in great savings over the life of a mission. Hence they contribute to *affordability*. These algorithms increase *reliability* in that they can design-in redundancy, fault tolerance, or defect tolerance at design time or *in-situ*. Examples include: fault-tolerance to extreme radiation or temperatures that damage programmable logic devices (eg, FPGAs). Evolvable systems algorithms can automatically design *modular* subsystems. Examples include evolving a modular robot made of identical components; evolving an generalized robotic controller algorithm.

H&RT Program Elements:

This research capability supports the following H&RT program /elements:

ASTP/Software, Intelligent Systems & Modeling
ASTP/Communications, Computing, Electronics, and Imaging
TM/All elements

Point of Contact:

Jason D. Lohn
(650)604-5138; jlohn@mail.arc.nasa.gov
http://ic.arc.nasa.gov/projects/esg

Ames Research Center